

Models of the Diffuse Radar Backscatter from Mars

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Earth-based, time-domain radar surveys of Mars exhibit a specular return from a sub-Earth region of Mars followed by diffuse returns from concentric rings that are centered on the sub-Earth point. A characteristic of the diffuse return is that the radar incidence angle increases from zero degrees at the sub-Earth point to nearly 90° at ring diameters that correspond to Mars' limb. An interpretation of the diffuse backscatter beyond inferences based upon the Rayleigh roughness criterion requires some assumption about the roughness statistics of the Mars surface, and requires a scattering theory that permits roughness at all scales. Our efforts during the first year of this project have focused upon the expected roughness statistics.

Several investigators have argued that natural surfaces are scaling [1, 2]. We explore that possibility through an Earth analog of a Mars volcanic region. The topographies of several debris flow units near the Mount St. Helens Volcano were measured at lateral scales of millimeters to meters in September 1990. Mount St. Helens was chosen because of its ease of access and its extremely young terrains. Our objective was to measure the surface roughness of the debris flows at scales smaller than, on the order of, and larger than the radar wavelength of common remote sensing radars. We used a laser profiling system and surveying instruments to obtain elevation data for square areas that varied in size from 10 cm to 32 m. The elevation data were converted to estimates of the power spectrum of surface roughness. The conversions were based upon standard periodogram techniques, and upon a modified spectral estimation technique that we developed.

The surfaces that we examined were located in the debris avalanche west-northwest of the volcano, along the North Fork Toutle River Valley. Most of the debris was deposited during and immediately after the eruption of Mount St. Helens on 18 May 1980. Since then, the deposits have undergone significant erosion by wind and water. A geologic description of the debris avalanche is given by Glicken [3].

Laser Profiler. A 2D laser profilometer was developed specifically for this experiment. Its main component is a surveying electronic distancemeter (EDM) which uses an infrared laser to measure distance. The EDM is mounted on an XY table that is supported 1.5 m above the ground (the minimum range of the EDM) by 4 tripods. Stepper motors are used to move the mounting platform across the table in both directions, allowing the EDM to scan a 1 m^2 surface area. The stepper motors and the EDM are controlled by a laptop computer, allowing the system to run unattended after startup. DC power is provided by two 12 V marine batteries.

Debris surfaces were spray-painted to increase reflectivity. The EDM laser has a spot diameter of $\sim 1.5 \text{ mm}$. In its most precise mode, the standard deviation of the measured surface height is 3 mm. Because each measurement requires 2–3 seconds, a typical scan of $10 \text{ cm} \times 10 \text{ cm}$ with sample interval $\Delta = 2 \text{ mm}$ (2601 points) takes ~ 1.8 hours. Since time was a limiting factor, an increase in surface area required a corresponding increase in Δ . Scans were performed at each site using at least two sampling intervals. A typical surface height grid is shown in Figure 1.

Surveying. Larger-scale topography was surveyed with a self-leveling level and stadia rod. Square grids with sides of 16 or 32 m were delineated by cables with markers at 1 m intervals. A typical survey grid is shown in Figure 2.

Surface Spectra. Estimates of roughness power spectra were developed from the elevation

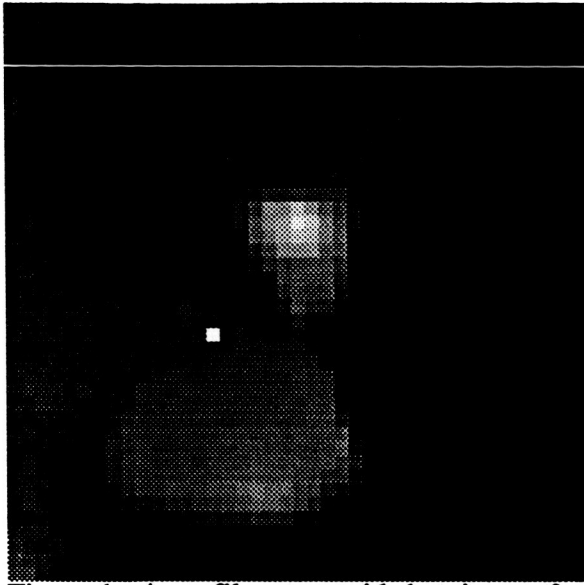


Figure 1. A profilometer grid showing surface height (dark = low). The grid measures 40 cm x 40 cm, with data points spaced 1 cm apart. Total height variation is 10.76 cm.

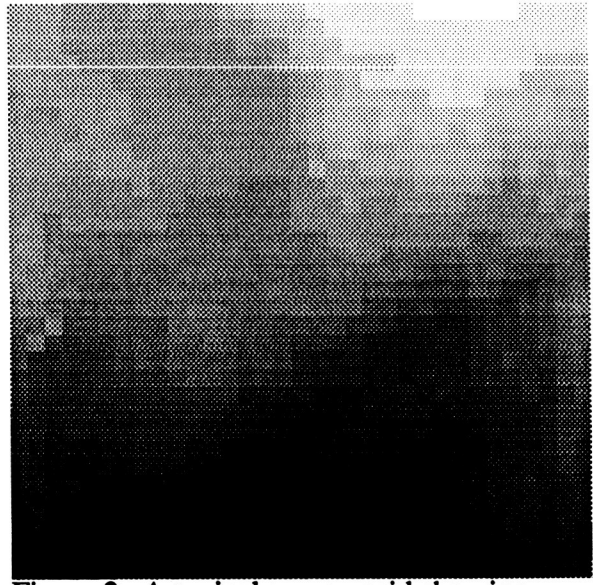


Figure 2. A typical survey grid showing surface height (dark = low). The grid measures 32 x 32 m, with data points spaced 1 m apart. Total height variation is 8.28 m.

data, but the processing steps differed for profilometer and survey data. Profilometer data suffered from errors which prevented use of standard spectral estimation techniques. These errors were of two types: (1) incorrect height impulses due to overheating of the EDM, and (2) intermittent level shifts due to instability in the EDM. Removal of errors due to overheating involved a combination of median and quartile difference filtering, and is fully described in [4].

Level shifts of 2-7 mm often occurred after 20-30 minute periods of normal EDM operation. This caused subtle horizontal bands in the profilometer scans. Although these level shifts were small compared to variations in topography, they might corrupt spectral estimates enough to make their elimination worthwhile. We developed a procedure of spectral estimation by linear sampling in which we assume that the surface statistics are isotropic. Linear profiles (rows of the profilometer scan) then become samples of the surface. By using individual scan rows (and removing the mean surface height or dc level from each), we avoid the level shifts because the reference level is stable within most rows. Rows in which level shifts occur are discarded. Furthermore, averaging the autocorrelation estimates obtained in different rows reduces the effect of any remaining impulse errors as well as the variance inherent to a surface random process. The assumption that the surface statistics of the debris flows are isotropic is justified by observation. The debris flows showed no directional structure.

The algorithm for obtaining a spectral estimate from linear profiles is developed rigorously in [4]. We show that if the the surface height $Z(x,y)$ is a wide-sense stationary random process that is ergodic in correlation, and if the x direction is along the row of the profilometer scan, then the autocorrelation function $R_Z(r)$ ($r^2 = \delta_x^2 + \delta_y^2$) for an isotropic surface is

$$R_Z(r) = R_Z(\delta_x, 0) = \lim_{T_y \rightarrow \infty} \left[\frac{1}{2T_y} \int_{-T_y}^{T_y} dy \lim_{T_x \rightarrow \infty} \left\{ \frac{1}{2T_x} \int_{-T_x}^{T_x} dx Z(x + \delta_x, y) Z^*(x, y) \right\} \right] \quad (1)$$

We use a lag window in our spectral estimate to reduce side lobes and to assure a positive spectral estimator. The window, $W(r)$, which is analogous to the Parzen window used in 1D spectral estimation, is:

$$W(r) = \left(\frac{2}{\pi}\right) \frac{1}{2a^2} \Pi\left(\frac{r}{2a}\right)^{**2} \quad (2)$$

where $a = (N_x - 1)\Delta$, N_x is the number of samples in direction x , Δ is the sample interval, Π is the 2D rect function which is centro-symmetric, and $**2$ indicates that the function is convolved with itself in two dimensions. The spectral estimation then becomes:

$$\hat{S}_Z(k) = 2\pi \int_0^{(N_x-1)\Delta} dr \, r R_Z(r) W(r) J_0(kr) \quad (3)$$

where J_0 is the zero-order Bessel function. $S_Z(k)$ is therefore the Hankel transform of $R_Z(r)$. A typical plot of $S_Z(k)$ is shown in Figure 3.

SURVEY SPECTRA. Spectral estimates from the survey data were more straightforward in that a standard spectral estimator, the periodogram, was used in the estimation of the survey spectra. A typical periodogram estimator resulting from the survey data is shown in Figure 4.

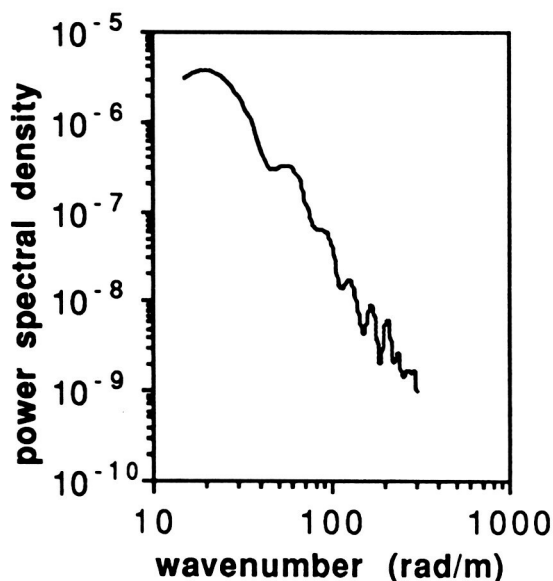


Figure 3: Surface spectral estimator $S_Z(k)$ for a typical profilometer scan.

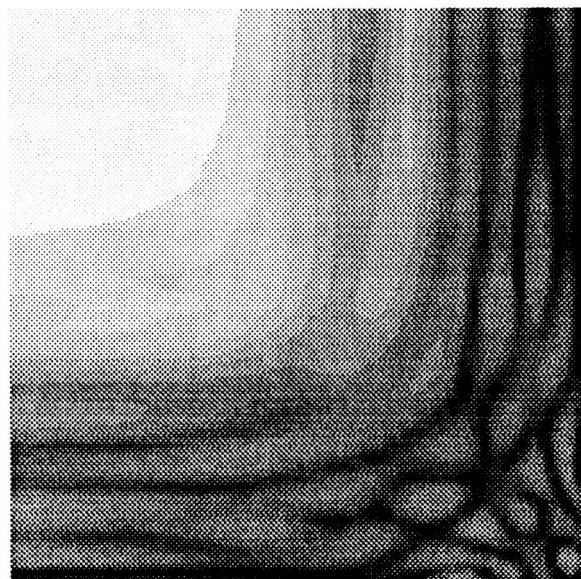


Figure 4: Periodogram spectral estimator for a typical surface survey.

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